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SILICOSIS AMONG MINERS

BY

R. R. SAYERS

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SILICOSIS AMONG MINERS

By R. R. SAYERS[1]

INTRODUCTION

Dust in any mine may be a health hazard. In bituminous or subbituminous coal mines it may also be an explosion hazard, but the present discussion is limited to the effects on men of breathing certain dusts in mines. Some dusts may cause disease by their poisonous action—as dust from lead, arsenic, or mercury ores. Other dusts, when breathed, irritate the lungs and cause a disease known by the general name of "pneumoconiosis." This lung disease is called "silicosis" when it is due to breathing rock dust (especially fine silica), "anthracosis" when due to breathing coal dust, and "siderosis" when due to breathing iron dust. Silicosis is also known as miners' phthisis or miners' consumption. Anthracosis is sometimes called coal miners' phthisis or coal miners' asthma. Breathing dust sometimes results in or predisposes to bronchitis and other respiratory diseases.

EARLY INVESTIGATIONS

The most important of the lung diseases caused by breathing dust is silicosis. That silicosis is produced by or is associated with breathing rock dust has been known by many for centuries, as is indicated by the literature.

Dr. E. L. Collis (1)[2] gives a very complete report on the literature from the time of Hippocrates up to the present. Hippocrates spoke of the metal digger as a man who breathed with difficulty and had other symptoms similar to those found in silicosis. Agricola, in 1557, stated that—

> Some mines are very dry and the constant dust enters the blood and lungs, producing the difficulty of breathing the Greeks call asthma. When the dust is corrosive it ulcerates the lungs and produces consumption, hence it is that in the Carpathian Mountains there are women who have married seven husbands, all of whom this dreadful disease has brought to an early grave.

[1] Chief surgeon, Bureau of Mines; surgeon United States Public Health Service.
[2] See pages 23 to 24 for references in parenthesis.

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Löhneiss, in 1690, referring to miners, describes the effects on them as follows:

> The dust and stone fall upon the lungs, the men have lung disease, breathe with difficulty, and at last take consumption.

In 1713 a British patent was granted for grinding flint by wet methods. Previously the flints were pounded dry which—

> Proved very destructive to mankind, so much that any person, ever so healthful and strong, working in that business can not possibly survive over two years, occasioned by the dust sucked into his body by the air he breathes.

In 1862 Doctor Peacock gave a report based on an examination of over 600 miners, in which he established the existence of miners' disease, distinguishing it from true phthisis, stating that—

> The quickness of pulse, the rapid and extreme emaciation, and the night perspiration so characteristic of true phthisis are generally absent or only slightly marked.

In 1902 a committee, of which Dr. J. S. Haldane was a member, reinvestigated the causation of the high phthisis mortality among Cornish tin miners, and decided that—

> So far as the Cornish miners are concerned it seems evident enough that stone dust, which they inhale, produces permanent injury to the lung, gradually in the case of ordinary miners, and rapidly in the case of machine-drill men. * * * That the primary injury to the lung is due solely to the inhalation of dust would seem to be practically certain.

PREVALENCE OF SILICOSIS

AUSTRALIA AND NEW ZEALAND

The disease is known to exist in a great part of the hard-rock mining districts of the world. It was studied in Western Australia by Dr. J. H. L. Cumpston, who reported in 1910 (4). He found that the death rate from respiratory diseases among all male nonminers over 15 years of age was 167 per 100,000, whereas the rate among miners was 539 per 100,000. The death rate due to tuberculosis among males over 15 years of age was 6, whereas among miners it was 192 per 100,000.

In 1921, among 6,538 miners at Broken Hill, New South Wales, 373 were found to have some incapacity due to effects of dust on the lungs (29).

In 1922, in New Zealand (23) 2,012 men were employed in gold mines, of whom 1,438 worked in quartz gold mines. During that same period 506 former gold miners received an annual compensation for incapacity due to effects of silica dust.

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SOUTH AFRICA

More work has been done in South Africa than in any other country on the study of silicosis, as a far greater number of men, from 12,000 to 15,000 whites and about 180,000 blacks, in a limited region are exposed to rock dust containing a high percentage of silica. For the years 1908–1909 the Miners' Phthisis Commission of South Africa (14) considered that out of a mining population of 12,000, approximately 1,000 men in any one year would reach the stage of definite incapacitation.

On account of the heavy morbidity from miners' phthisis, a Miners' Phthisis Medical Bureau was established in Johannesburg in 1916 under Government auspices (28). By periodical examinations of the miners actually employed, 738 were found to be suffering from simple silicosis in the year 1916–17, 700 in the year 1917–18, 704 in the year 1918–19, 1,572 in 1919–20 (this year the antiprimary stage was included), 448 in the year 1920–21, and 434 in the year 1921–22.

GREAT BRITAIN

In Great Britain the subject has been studied thoroughly by Doctor Haldane, Doctor Collis, and others. The statistics collected by Doctor Collis (2) for all occupational groups show that the death rate for tin miners from phthisis is greater than in any other industry in any period given. In 1910–1912 the rate of death from phthisis was 75 among coal miners, as against 678 among tin miners; so phthisis presumably is closely related to tin mining.

In another paper (3) Doctor Collis states that the incidence of phthisis among coal miners, although low, and that of other respiratory diseases which is often high, are probably influenced by exposure to dust. He further states that tin and lead miners suffer from typical silicosis, the results of which are associated with the high mortality of other respiratory diseases and Bright's disease.

UNITED STATES

Investigations have shown that silicosis is present in many of the mining districts of the United States. In Missouri (17 and 12a), in the Joplin district, Doctor Lanza found that 433 miners out of 720 examined had silicosis. He also found that 432 out of 1,018 examined in Butte (12) were so affected. The disease has been found in Nevada, Idaho, Arizona, and California. Jarvis and Hoffman (13) and others have shown the mortality from this disease to be very high among granite workers in Vermont.

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TABLE 1.—*Average death rates per 100,000 miners and general population in certain States for 1917–1920, and granite cutters in the United States and Canada for 1915–1918*[a]

Diseases	California			Colorado			Illinois[b]			Indiana			Missouri			Nevada[c]			United States and Canada
	Coal miners	Metal miners	General population	Coal miners	Metal miners	General population	Coal miners	Metal miners	General population[d]	Coal miners	Metal miners	General population	Coal miners	Metal miners	General population	Coal miners	Metal miners	General population	Granite cutters
Silicosis		34.66		66.17	609.32		[e]0.55										95.22		
Tuberculosis		664.45	155.7	76.12	154.40	205.60	109.21		104.30	88.53		105.75	91.09	[f]1,946.70	117.3		298.06		[g]1,044.3
Influenza		162.56	124.6	110.97	644.72	177.85	128.02		143.96	173.42		100.20	214.98	602.24	102.5		149.23		
Pneumonia		521.70	133.5	420.40	2,182.09	184.87	151.12		162.66	96.25		144.72	92.60	338.10	178.8		656.98		
Other respiratory diseases		127.86		39.19	137.97		33.51			94.24			16.49	39.41			51.91		
All diseases		3,564.47	1,457.5	2,045.00	6,167.25	1,715.00	1,300.41		1,360.00	1,372.78		1,397.50	971.00	4,317.04	1,342.5		2,635.62	847.85	

[a] Exclusive of the last three months of 1918.

[b] Data for Illinois are for 1916–1919.

[c] Nevada is not in registration area and the population has been estimated.

[d] No figures given for 1917 by Census Bureau as Illinois was not in registration area at that time.

[e] Anthracosis.

[f] The high death rate for metal miners in Missouri may be fallacious. Many of the miners still residing in Jasper County (where the rate was much higher than in the eastern part of the State) travel by electric cars to their work in new developments in Oklahoma. Record of death gives place of residence and not place of work.

[g] Hoffmann, F. L Bureau of Labor Statistics, Bulletin 293, 1922.

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Table 1 gives the average death rates per 100,000 in certain States for silicosis, tuberculosis, influenza, pneumonia, and other respiratory diseases as well as for all diseases among coal miners, metal miners, and the general population for a 4-year period. The rate for tuberculosis among granite workers of the United States and Canada is also given for comparison, as this occupation is known to predispose to this disease. Table 1 shows that the death rate due to silicosis and tuberculosis, among metal miners of the States given, is much higher than the death rates due to these diseases among coal miners or among the general population. The rates for these two diseases can be combined, as they are usually associated in this industry.

CONDITIONS PROMOTING SILICOSIS

That no nationality is exempt and that all races are susceptible is shown by the wide distribution of silicosis. Although the incidence is higher among the younger miners in districts where the percentage of free silica is high, and among older miners where the percentage of silica is low, age in itself probably is no great factor.

Previous occupation of the men may have a definite influence in predisposing to silicosis, if they have been exposed to dust or to other respiratory irritants.

Men who have worked in certain coal mines for several years seem to be less susceptible to silicosis than the average man. According to some investigators, animal experiments indicate that coal dust has this effect. Three groups of animals were exposed for a definite time as follows: Group 1 to free silica dust, group 2 to a mixture of coal dust and silica dust, and group 3 first to coal dust and then to silica dust. They were examined several months after exposure, and groups 1 and 2 had more silica remaining in the lungs than group 3, although silica dust could be demonstrated in all groups (18).

Men who have or have had respiratory diseases, especially tuberculosis, are apparently more readily affected by silica dust.

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TABLE 2.—*Percentage of constituents in rock, whose dusts are known to have caused silicosis*

Constituents	Joplin, Mo.[a]	Tonopah, Nev.[b]		Butte, Mont.[b]			Waihi, New Zealand[c]				Vermont[d]		Rand[e]	Broken Hill Australia[f]	
		Sample as received	Dry sample	Country rock	Machine cuttings	Drill cuttings	Ore	Mill sample dry crushed	Martha No. 7.	Sulphide band, Martha No. 7	Barre	Bethel		Country rock	Ore
Silica (SiO_2)	From 98.17 to 99.46	78.9	79.1	65.1	62.51	61.50	90.80	95.97	86.76	59.55	69.89	77.52	87.40	62.00	
Silica (free)															12.23
Silicates															44.57
Aluminum oxide (Al_2O_3)	Al_2O_3 and Fe_2O_3 0.83 to 0.29	8.5	8.5	14.5	11.82	14.12	2.89	1.62	5.22	7.02	15.08	16.78	9.80	16.50	
Iron (Fe)				4.6	7.43	5.77							1.75		
Iron sesquioxide (Fe_2O_3)		5.4	5.4				.82	.93		4.80	1.04			.20	
Ferrous sulphide (FeS)							2.48	.93	.72	4.80					
Iron oxide (FeO)											1.46	.84		6.80	
Magnesium oxide (MgO)	0.01	.8	.8	.9			.15		2.20	9.79	.66	.32	Trace.	1.00	
Manganous oxide (MnO)		1.6	1.6				.43	.24						2.50	
Lime (CaO)	From 0.05 to 0.04	.3	.3				.69	.25 Alk .11		3.12 Alk.1.28	2.07	2.56	Trace.	1.30	
Soda (Na_2O)				.3							4.73	1.21		1.20	
Potash (K_2O)				3.4							4.29	.62		4.00	
Titanium dioxide (TiO_2)					1.04								Trace.	2.10	
Copper (Cu)					1.42	1.35									
Sulphur (S)				4.4	9.27	11.20							1.10	.10	
Sulphides of copper															.22
Sulphides of arsenic and antimony															.06
Calcium carbonate ($CaCO_3$)															14.84
Calcium floride ($CaFe_2$)															.11
Pyrite or marcasite															.11

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Pyrrhotite															.90
Arsenic (As)					.256	.47									
Lead (Pb)						1.73									
Zinc (Zn)						3.31									
Manganese (Mn)				.1											
Carbon dioxide (CO_2)		3.0	3.0												
Galena															15.94
Blende															21.89
Moisture (H_2O)		.2												1.90	
Loss on ignition	From 0.78 to 0.34	.3	.3				1.39	.88	5.10	6.40					
Undetermined				ø6.78	ø6.25		.32				.54	.33			
Total	99.84100.13	99.0	99.0	100.0	100.00	99.45	99.97	100.93	100.00	100.26	99.76	100.18	100.05	99.50	100.61

[a] Higgins, Edward, Lanza, A. J., Laney, F. B., and Rice, G. S., Siliceous dust in relation to pulmonary disease among miners in the Joplin district, Mo.: Bull. 132, Bureau of Mines, 1917, p. 102.

[b] Analyses made by Bureau of Mines. The Tonopah, Nev., samples were taken from average vein matter.

[c] The geology of the Waihi-Tairua subdivision, Bulletin No. 15 (new series), Department of Mines, New Zealand, pp. 135–137. (Other ores in this district vary greatly.)

[d] The problem of dust phthisis in the granite stone industry, Bureau of Labor Statistics, Bull. 293, p. 109.

[e] General Report of the Miners' Phthisis Prevention Committee, South Africa, for 1916, p. 182.

[f] Report of the Technical Committee of Inquiry, New South Wales, 1921, p. 61.

[ø] By difference.

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EFFECTS OF ROCK DUST ON THE LUNGS

Table 2, which gives analyses of rocks whose dusts are known to have caused silicosis, shows that all the rocks listed contain a large percentage of free silica, excepting the rock from Broken Hill, Australia. It is accepted that free silica produces a fibrosis (formation of scar tissue) of the lungs more readily than other dusts. However, some other dusts, if enough of them is breathed, may produce a fibrosis, but of a different type, as in Australia. The quantity necessary to cause symptoms and to result in lessened capacity for work varies with the individual dusts.

THEORIES OF THE CAUSE OF HARMFULNESS OF SILICA DUST

A number of theories are given as to why silica or quartz dust is the most harmful. The one to be given first and still accepted by many is the physical characteristics of the particles of dust, their sharp knife like and needle like form, and their insolubility. (Pl. I, p. 14.) But it has been pointed out that some dusts having these physical characteristics, as carborundum (6), do not readily produce fibrosis. Furthermore, if the harmful effects are due to the ability of the particles to penetrate tissues, they should penetrate all soft body tissues, and this has not been found true. Doctor Haldane (10) notes that silica dust without sharp and pointed particles, as precipitated silica, heated enough to dehydrate, if inhaled will cause changes similar to those produced by quartz dust.

Some investigators think that silica exerts a toxic action upon the tissue cells. In support of this, Myers (22) found that silica dust collected in the mines of the Joplin-Picher district is soluble in water. Doctor Mavrogordato (18) reports that silica is soluble in weak alkaline solutions similar to body fluids. He concludes that the solubility and chemical activity of silica are of great importance, and that hardness and sharpness are of but little importance in causing silicosis, also that ultramicroscopic particles or chemically inert dusts are not dangerous. Doctor Mavrogordato reports that possibly silica dust exerts preservative action upon the cells which take it up, that is not exerted by inert dust. Doctor Gye and Doctor Kettle (8) found that colloidal silica, when injected into animals, is poisonous. Doctor Gye is of the opinion that the toxicity varies directly with the solubility of silica (9).

In reviewing these theories, Doctor Haldane states that enough work has not been done to decide definitely which is correct.

He, however, thinks that the most probable theory is "that dusts produce phthisis in proportion as they are physiologically inert." He

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thinks that they act by being in the way, and when enough particles are in the cells the life processes of the cells are slowed.

Most of the experimental evidence favors the theory that silica is soluble enough in water and in weakly alkaline fluids to be toxic, and that it causes silicosis more rapidly than other dust, due to its action as a protoplasmic poison. Although more investigation is needed to determine the facts, nevertheless there is good empirical evidence that dust containing a high percentage of free silica is most dangerous; furthermore, that only the very fine particles reach the lung tissue and remain there. The particles found by Doctor Watkins-Pitchford and Doctor Moir (20) in the lungs of miners on the Rand were mostly less than 5 microns (1 micron = 1/25,000 of an inch) long; only 1 particle in 2,000 was over 8 microns, and only 1 in 1,000,000 was as much as 14 microns long. When it is remembered that the cells, which take up the particles of dust, usually measure about 10 microns in diameter, larger particles evidently can not be ingested.

REACTION OF THE LUNGS TO DUST PARTICLES

Much of the dust, especially the larger particles, is deposited in the upper air passages. Some of the fine dust, 10 microns long or less, is deposited on the surface of the alveoli. Part of the air passages is covered with cilia (hairlike processes) which are in constant motion, tending to sweep out any foreign matter.

The fate of the dust taken into the alveoli of the lungs (terminal air sacs of the lungs) has been carefully studied. Doctor Mavrogordato (18), discussing results of the more recent investigations, says that when any dust gets into the lungs a large number of cells, "dust cells," are produced which take up the particles of dust. Many of the dust-ladened cells escape into the air passages and are coughed up and expectorated. Those that remain in the lungs become fixed and may be dangerous. The life of dust cells is normally brief. They may be carried off by the lymphatics or may die and be digested or dissolved by the body fluids and leave any dust, previously ingested, on the adjacent tissues. When coal dust is breathed and ingested by dust cells, the dust particles can be found after a few weeks outside these cells on the outer surface of the blood vessels of the lungs at points where the cells have died and been digested or dissolved. Much of this dust can and does escape into the air passages to be coughed up. Doctor Mavrogordato concludes that "it is the dust which can not escape from the tissues which is a source of danger, and as long as elimination follows fairly closely upon the heels of ingestion not much harm is done. Coal seems to set up a sort of aseptic 'catarrh' in which there is a steady exodus of particles from the lungs."

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EFFECTS OF SILICATE DUSTS

Dust from hard rock, containing no free silica but composed entirely of fine spicular hard minerals, of which 89 per cent was estimated as feldspar and the rest pyroxene and other dense minerals, when breathed, remained within the cells. The dust particles seem to have exerted, according to Mavrogordato (18), some protective influence over the cells containing them, preventing the death and autolysis of the cells. The Miners' Phthisis Medical Bureau of South Africa has detected no fibrosis of a silicotic type among workers in the quarry producing this stone.

Among miners of Broken Hill, Australia, where the stone contains an average of 12.23 per cent of free silica and 44.57 per cent of silicates, the men develop a fibrosis of a different type from that due to free silica. The lung tissue of men suffering from this type of silicosis is not so dense as that of men suffering from silicosis caused by free silica. Furthermore, the X-ray findings are somewhat different and the appearance is described as soft (29). (Pl. IV, p. 15.)

EFFECTS OF FREE-SILICA DUST

When dust of free silica is breathed, the particles ingested by the dust cells, unlike coal dust, remain within the cells. The cells become clumped together to form a mass similar to the masses of cells (tubercle) found in tuberculosis. These masses of cells, pseudo (false) tubercles, are first found near the surface of the lungs. At first they are separate; later they become confluent and assist in uniformly thickening the pleura (covering of the lungs).

Cells containing silica particle do not die and are not digested or dissolved by the body fluids as are those ingesting coal dust. When these dust cells reach the lymphatics, they are not all carried off but accumulate and block the lymphatics. The cells gradually merge into fibrous tissue (scar tissue). The blood vessels may be surrounded by the fibrous tissue but may remain open or become plugged with the cells and finally filled with fibrous tissue.

The earliest changes due to breathing silica dust in sufficient quantities are: 1, Accumulation of dust cells in masses or psuedo (false) tubercles immediately under the pleura; 2, formation of free psuedo tubercles; and 3, blockage of the lymphatics.

In a well-marked case of simple silicosis, fibrosis has taken place in the psuedo tubercles and in the blocked lymphatics and blood vessels of the lungs, with a thickening of the pleura (18).

LENGTH OF TIME FOR DEVELOPMENT

Mavrogordato found that 6 months were required for the changes described to take place in animals. Doctor Gye states that in experiments carried out somewhat differently the changes could be demon-

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strated in about a year. In the gold mines of South Africa where the conditions are good, the average time of exposure of men before simple silicosis can be diagnosed is seven and one-half years; the shortest period of exposure is reported to be two and one-half years (19). From these statistics one would conclude that the length of exposure to silica dust necessary to cause silicosis varies, with the condition of exposure, from a few months to several years.

STAGES OF SILICOSIS

Silicosis has been arbitrarily divided into different stages in various countries. In the United States the stages are called first, second, and third; in South Africa they are defined by law as anteprimary, primary, and secondary. The earliest stage means that definite physical signs of damage to the lungs have been found, and that such damage has occurred during and in consequence of exposure to dust. The second stage means that definite and specific physical signs of silicosis are or have been present and that capacity for work has been impaired by that disease, though not seriously and probably not permanently. The third stage means that specific physical signs of silicosis are or have been present and that the capacity for work has been seriously and permanently impaired by the disease.

SYMPTOMS OF THE DIFFERENT STAGES

The symptoms of uncomplicated early silicosis are few and often indefinite. Slight shortness of breath on exertion, often with recurrent colds, is the most constant symptom. The general health is good. The patient may apparently be quite well and his working capacity not noticeably impaired. He may have a little less ability to expand his chest than formerly and the elasticity of the chest may be slightly impaired. This stage may exist for a long time.

As the disease progresses the symptoms increase in severity. No sharp dividing line exists between any of the stages. The second stage is indicated by a definite shortness of breath on exertion and perhaps flitting pains which attract the attention of the patient; also often by a morning cough, with little or no expectoration, and by more frequent recurrence of colds. Even then the patient's health may not be noticeably affected. He may not lose flesh and may appear quite robust. But his "wind is bad," he can not work as well as formerly, and his chest expansion is noticeably decreased. In well-developed cases of this stage the chest is held in a state of partial inspiration.

In the advanced, or third stage, the shortness of breath is marked and even distressing; the patient coughs more often; the expectoration is in most cases slight but may be more copious. The patient becomes unable to work, loses flesh, his expansion is greatly decreased even

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with a forced inspiration, his pulse rate is increased, and his heart may become dilated.

The cardinal symptom, it will be noticed, is shortness of breath, especially on exertion. The cardinal sign is diminished expansion of the chest. These symptoms are slight in the early stages. The cough is that of irritation and may be brought on by having the man take a deep breath; it can not, however, be considered as a cardinal symptom. Recurrent colds and pains in the chest are also important symptoms. The symptoms characteristic of tuberculosis—loss of appetite and strength, rise in body temperature, night sweats, and hemoptysis (spitting of blood)—are not found unless infection is present. Other symptoms and signs, especially the X-ray findings, are of great aid in diagnosing silicosis.

X-RAY DIAGNOSES

Doctor Watkins-Pitchford states (32) that the Miners' Phthisis Medical Bureau does not make a diagnosis for benefits without a perfect X-ray negative. An imperfectly made negative may lead to incorrect interpretation and a false diagnosis. The states diagnosed by clinical methods have usually paralleled those diagnosed by X-ray in the mining industry of this country and of South Africa. In the study of granite workers, Jarvis (15) made more subdivisions of the findings.

The X-ray of a normal chest (Pl. II) shows the heart shadow about the center of the picture, merging with the shadow of the diaphragm below and the big blood vessels and spinal column above. On each side of these are parallel shadows cast by the ribs. Between the shadows the picture is clear except for the shadows cast by the lung structures. The hilum, or root, of the lung is composed of the large blood vessels and bronchi; the shadows cast by these are on either side of the upper part of the heart shadow and are irregular in shape, with the shadows of the larger blood vessels radiating from them.

Dr. H. K. Pancoast (24) and Dr. S. B. Childs (17), in this country, and Dr. W. Steuart (28), of South Africa, have had extensive experience in interpreting X-ray pictures of the chest of cases of silicosis. The writings of these men have been carefully consulted and, although they describe the various stages in somewhat different language, the findings of all are about as follows:

The first change noted in the X-ray of a man who is developing silicosis is enlarged hilum shadows; that is, the shadows become denser and more extensive, gradually involving the smaller bronchi and in time forming a linear network (Pls. III and IV). In simple sil-

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icosis these changes are almost symmetrical throughout both lungs, except that the shadows are usually more marked toward the right base. All agree that these findings may be due to other causes and a definite diagnosis of silicosis in an individual case can not be made at this time on signs on the X-ray negative without clinical findings. For a group investigation, however, as that made in Broken Hill (29), diagnosis of pneumoconiosis in men who complained of no symptoms of ill health of any kind was made on the X-ray findings alone.

In the second stage, the hilum or root structure shadows are much denser and larger, the finer shadows found in early silicosis have increased in number and density, are less regular, and look beaded. Sometimes the effect is described as a generalized mottling. (Pl. V.)

In the third stage the entire area of both lungs is covered by many discrete well-defined rounded shadows. (Pls. VI and VII.)

EFFECT OF GOOD AIR

A miner suffering from simple silicosis generally improves—usually to recovery if in the first stage, materially if in the second, and somewhat if in the third—if removed from the dusty atmosphere and placed in suitable surroundings. Doctor Watkins-Pitchford (31) states that due to the effect of the silica that remains in the lungs the disease may progress for some time after the miner leaves the mine.

RELATION TO TUBERCULOSIS

Silicosis in any stage, but especially in the second or third, renders men more susceptible to tuberculosis than they normally are. When tuberculosis is diagnosed in such cases, immediate action should be taken to arrest the disease (Pl. VII). When any miner who has or has had silicosis develops a "cold" of more than three days' duration, he should be thoroughly examined and treated by a physician to arrest the disease at once.

DETERMINATION OF DUST IN THE AIR

If breathing a dust causes a disease, evidently the disease would not result if the dust were not in the air breathed. In order to control the dustiness of the air, the amount of dust present must be determined. Two factors are usually considered, the weight and the number of particles of dust in a given quantity of air. Many instruments have been devised for making these determinations, but any apparatus to be of value must be able to remove a large percentage of the dust from the sample of air and retain it in a form that may be examined.

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SUGAR-TUBE METHOD

Until recently the sugar-tube method has been found to be the most reliable for weight determinations. By this method air is drawn through a tube containing a given amount of granulated sugar, which may be dissolved later and the dust examined. Sugar tubes ranging from ¾ to 2½ inches in diameter have been used. The Bureau of Mines type B (Fig. 1) is made of molded glass, 2⅜ inches inside diameter. One hundred grams of sugar are used. This must pass through a 14-mesh but not through a 65-mesh screen.

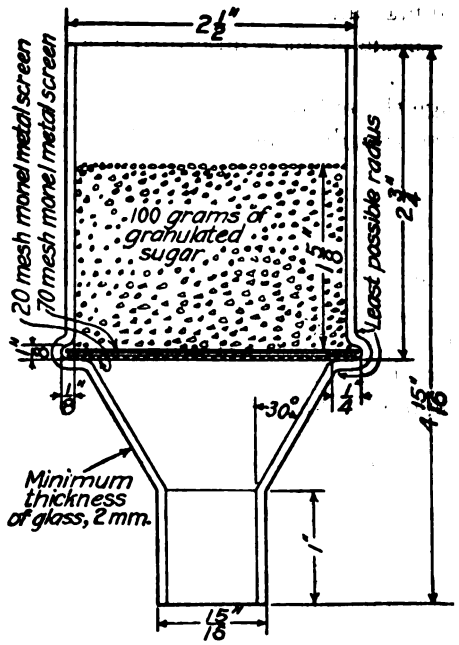

FIGURE 1.—Type B sugar tube used by the Bureau of Mines to collect dust samples

In South Africa this method is used almost exclusively for weights, but in the United States it is also used for dust counts and sometimes for chemical and mineralogical determinations.

KONIMETER

The konimeter (Pl. VIII, *B*) was devised by Sir Robert Kotze (21) as a rapid method of estimating the number of particles of dust in mine air. By this instrument a small quantity of the air is forced at a high velocity upon a greased slide. The spots of dust adhering to the slide are examined under a microscope, through which the sizes and number of particles may be estimated. This instrument is of especial value in that determinations can be made very quickly.

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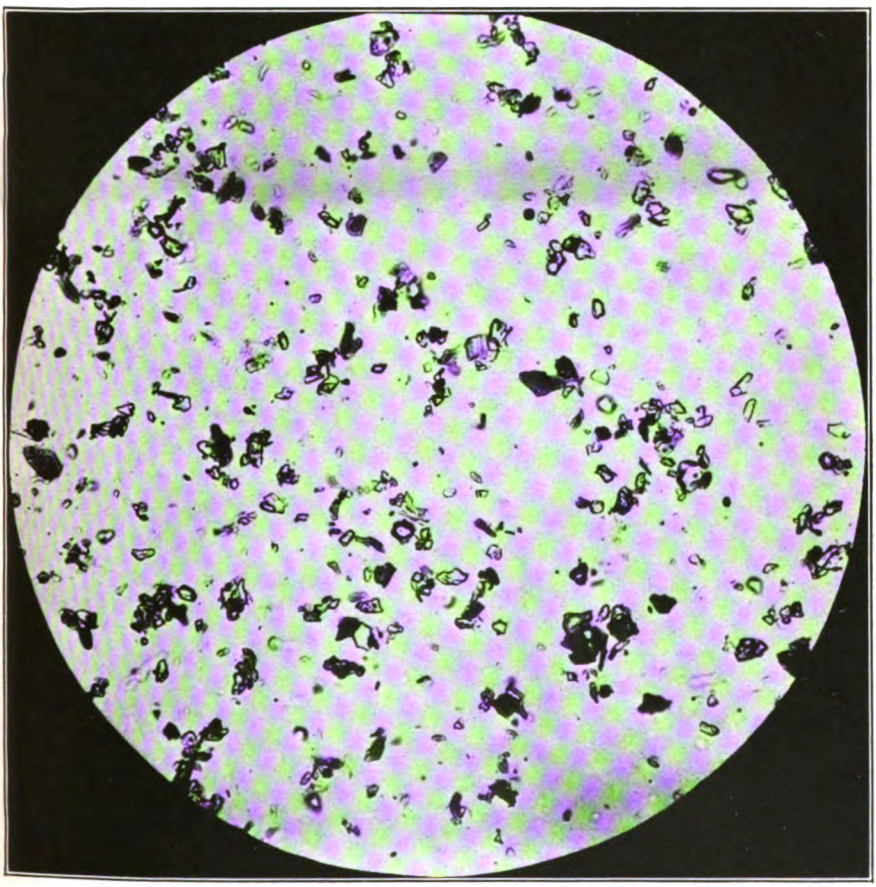

MICROPHOTOGRAPH SHOWING PHYSICAL CHARACTERISTICS OF SILICA DUST

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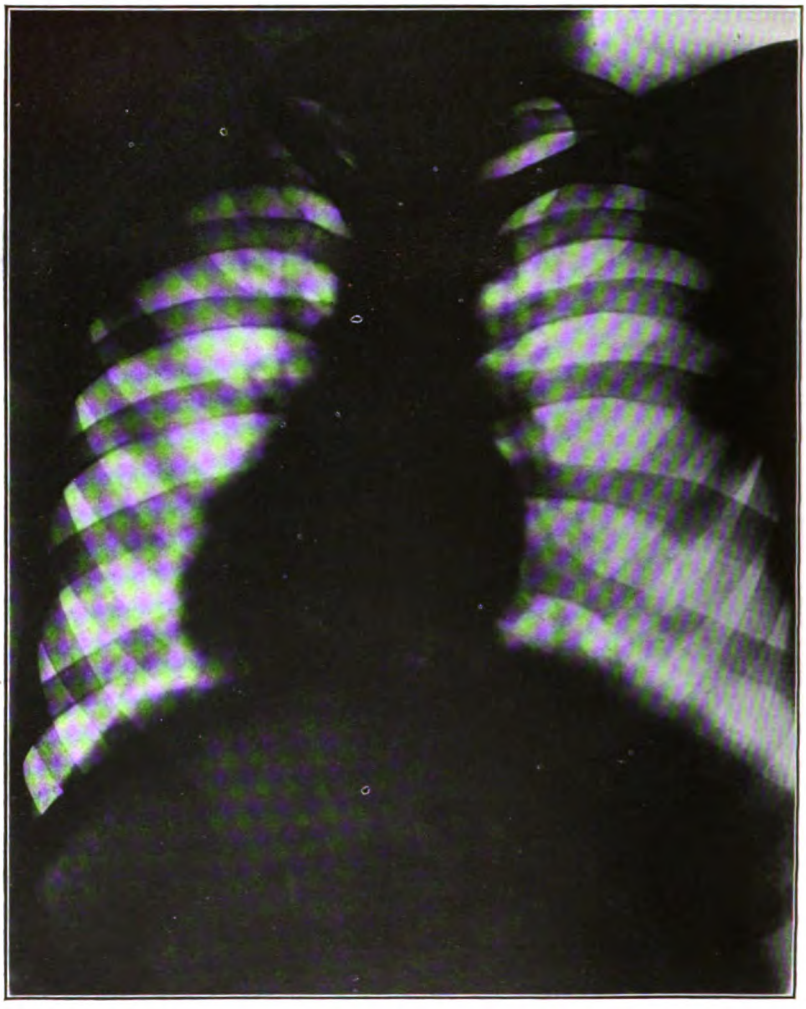

X-RAY SCIOGRAPH OF NORMAL CHEST

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FIRST STAGE OF SILICOTIC FIBROSIS. (FURNISHED BY COURTESY OF DR. WATKINS-PITCHFORD AND DR. L. G. IRVINE OF SOUTH AFRICA)

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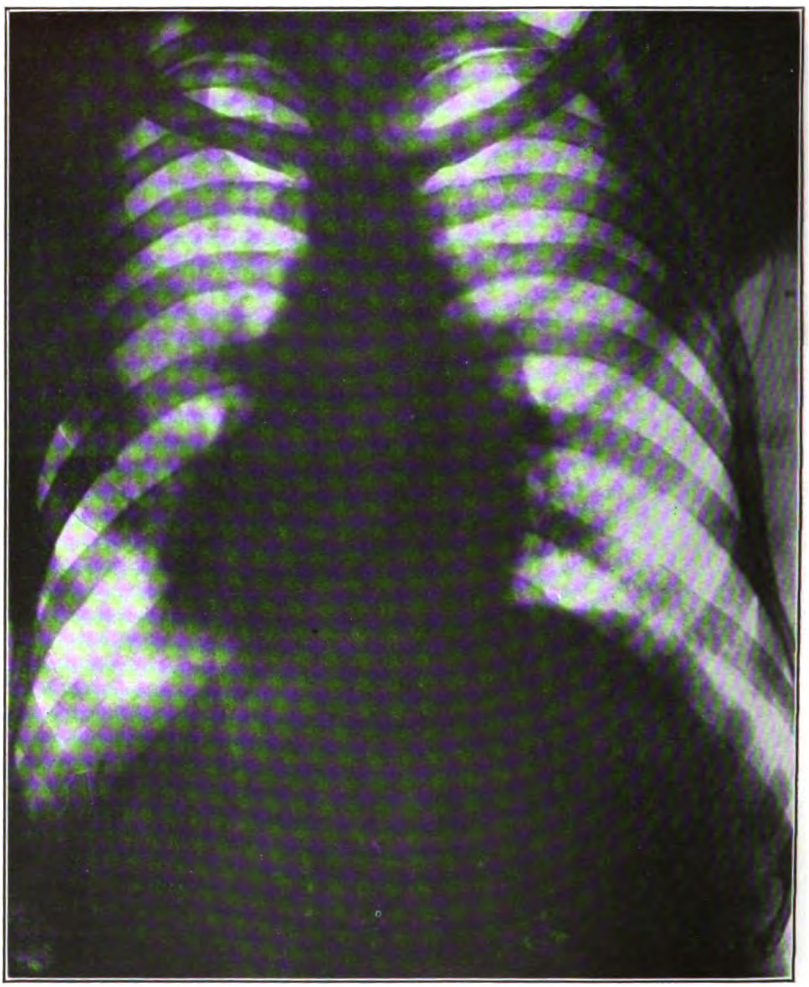

EARLY SILICOSIS, FIRST STAGE, SHOWING FINE MOTTLING OR "SOFT APPEARANCE"

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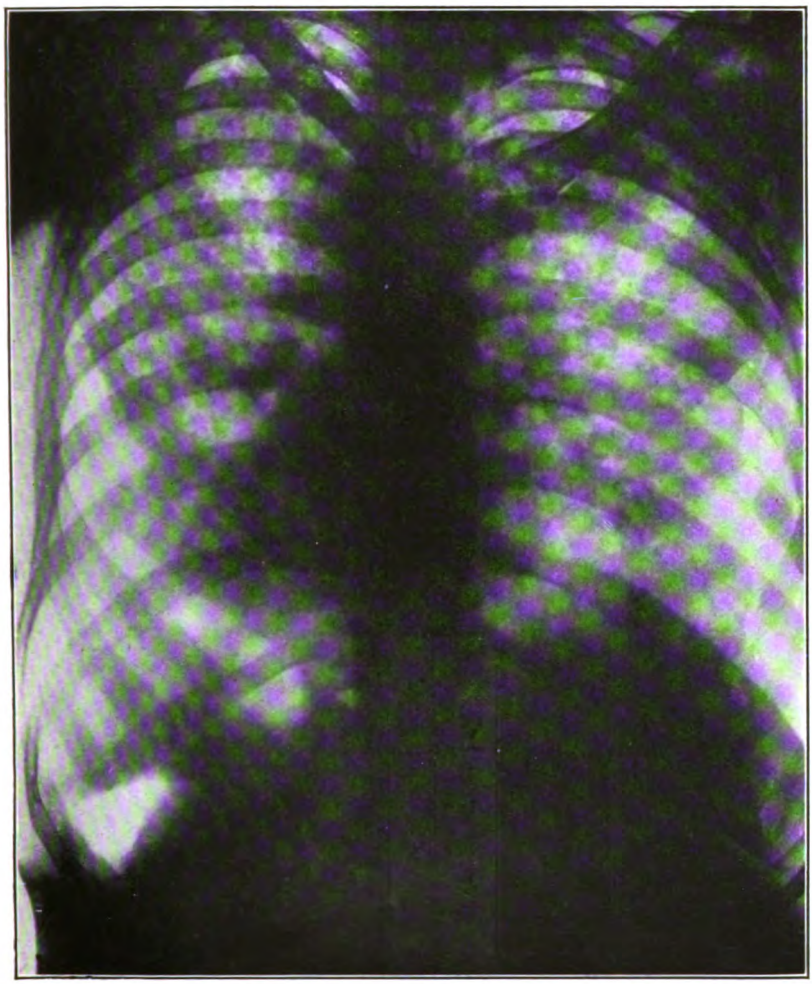

SECOND STAGE, MODERATELY ADVANCED SILICOSIS

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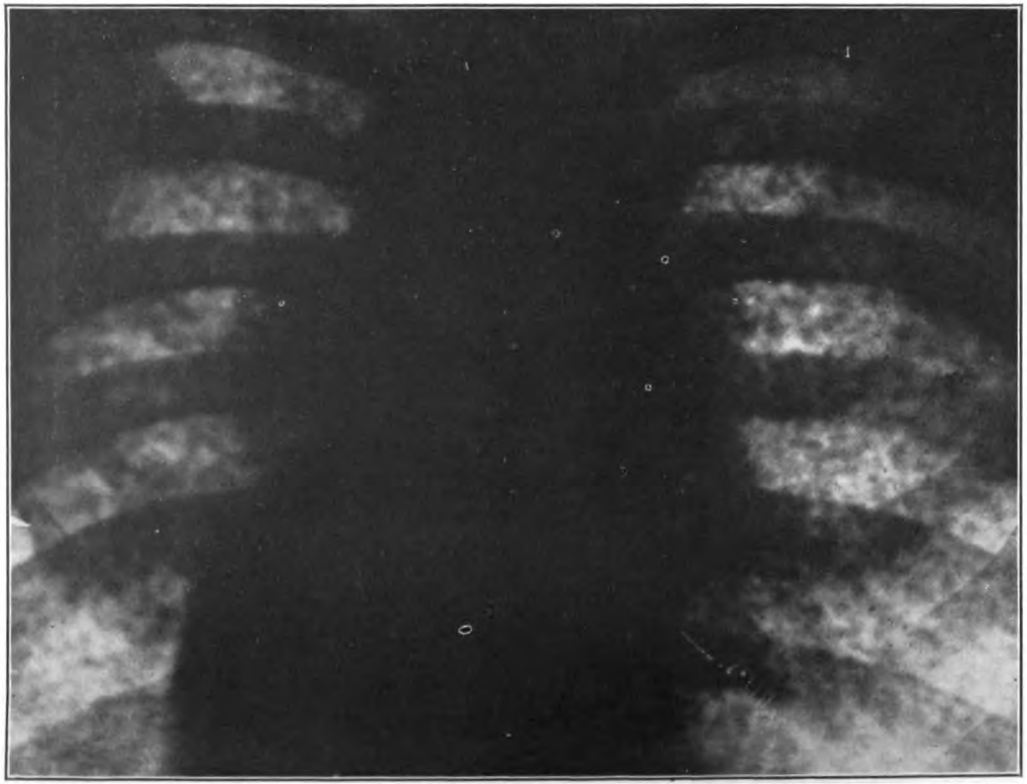

ADVANCED SILICOTIC FIBROSIS. (COURTESY OF DR. WATKINS-PITCHFORD AND DR. L. G. IRVINE OF SOUTH AFRICA)

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SILICOSIS COMPLICATED WITH TUBERCULOSIS

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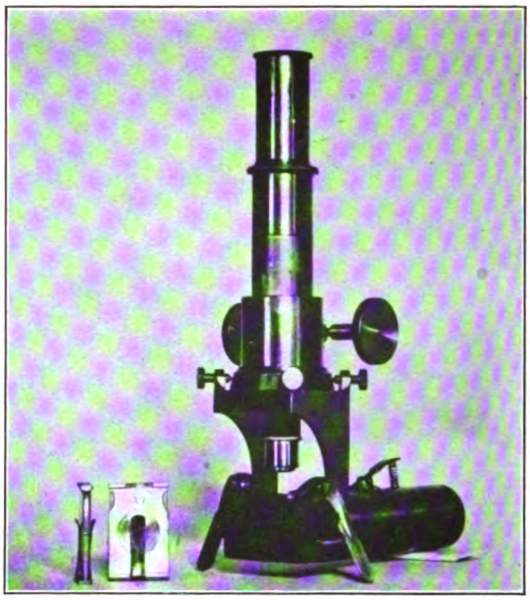
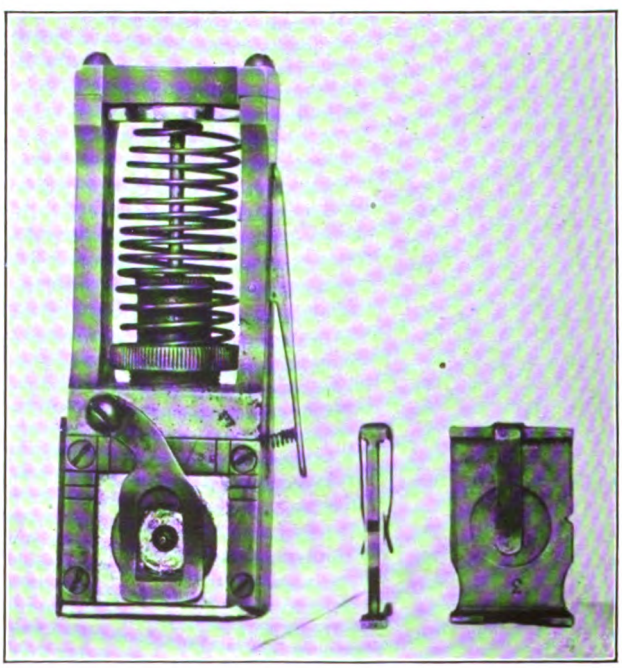


A. AUSTRALIAN MODIFICATION OF THE KOTZE KONIMETER



B. THE KOTZE KONIMETER

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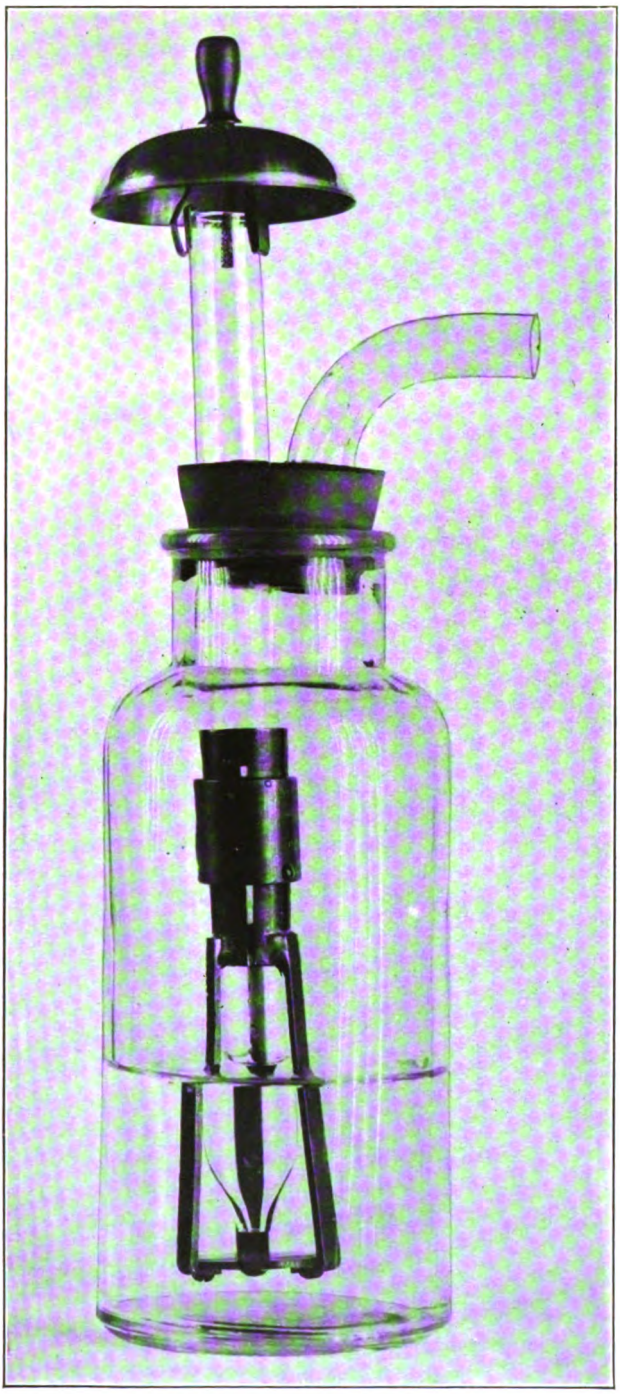

IMPINGER FOR COLLECTING DUST FOR LABORATORY ANALYSIS

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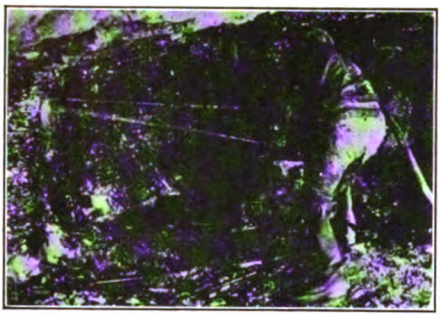
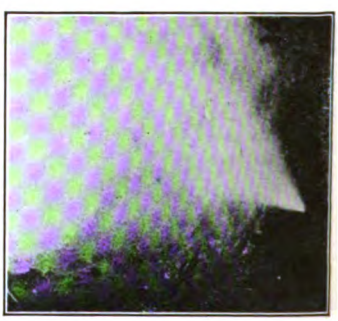


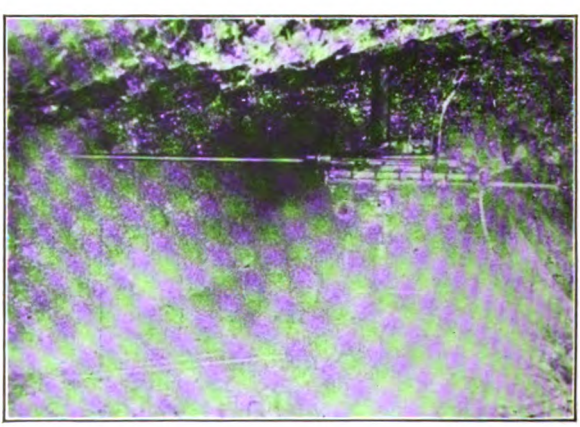
A. USE OF WATER WHILE COLLARING

C. LIGHTING THE SHOTS BEFORE TURNING ON THE WATER BLAST

B. WET DRILLING WITH A LEYNER DRILL



D. WATER BLAST TURNED ON



E. SHOWING DUST FORMED BY THE LEYNER DRILL WHEN THE WATER FAILS FOR 30 SECONDS

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Modifications of the konimeter and instruments similar to it have been developed in other countries. In Australia a microscope has been attached to an instrument operating on this principle and the inspector may thus make his determinations immediately. (Pl. VIII, *A*.)

IMPINGER

Recently another instrument (Pl. IX) using the impinger principle has been developed by Leonard Greenburg (7) of the United States Public Health Service and G. W. Smith of the Bureau of Mines. As the air is drawn through a liquid (alcohol or distilled water), it impinges upon a smooth surface. The present form is made of a half-inch tube gradually reduced at the tip from 0.5 to 0.118 inch (3 mm.) The impinging plate is circular and attached by three legs, 5 mm. distant from the end of the nozzle. The tube is inserted through holes in a rubber stopper which fits a 5-c. c. conicle-shaped beaker containing 100 c. c. of liquid. This instrument gave 86 per cent efficiency when 28.3 liters per minute of air were drawn through; 91 per cent with 32 liters; and 92 per cent with 35 liters.

Disadvantages of the impinger are: 1, Dusts soluble or affected by water can not be determined, but alcohol or other liquids which do not attack the dusts may be used; and, 2, samples can be preserved only a short time, when slightly soluble in the liquid, and should be analyzed without delay. The advantages are: 1, Errors due to impurities in materials are low and unimportant, so that low concentrations of dust may be determined with comparative accuracy; 2, laboratory analysis is rapidly made; and, 3, absolute dustiness, independent of relative dustiness, is most nearly expressed by the impinger analyses.

The impinger collects the dust in large volumes of air apparently as efficiently as the sugar tube and retains it in a condition that makes a complete laboratory examination much simpler.

OTHER DEVICES

Many other instruments are apparently giving satisfaction and deserve mention. Among these are the Read water-spray dust collector, the Kotze hydrokonimeter of South Africa, the Owen dust counter, and the electric dust collector of Philip Drinker (5).

METHODS OF PROTECTION AGAINST DUST

The instruments mentioned will give information as to the condition of the air but will not aid in any way to protect the men breathing it. The men will be protected: 1, If no dust is formed; 2, if, when formed, the dust is prevented from getting into the air; 3, if once in the air the dust is removed from the air; and 4, if the dusty air is replaced by clean air.

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WET DRILLING

Collaring may be an important source of dust with any type of drill, unless water is properly used. In collaring, the full bore of the hose should be used in supplying water to the collar. The face should be thoroughly wet before drilling begins. (Pl. X, *A*.)

Statistics indicate that silicosis usually occurs earlier and in a higher percentage among drillers than among other miners. Drills with outside water jets cause somewhat less dust than dry drills. Axial-feed water drills of the Leyner type and wet-head axial-feed water stopers have been introduced into the mines of South Africa, in some mines in Australia and New Zealand, and in various districts of the United States, to the advantage of both the company and the miner. Recent reports (25) indicate that the drills not only produce less dust but drill more rapidly.

The typical Leyner drill (Pl. X, *B* and *E*) allows some air to pass down the axial tube with the water to the bottom of the hole. This air and water mixture, as it comes from the drill hole, has been found to contain rock dust. Rock dust is just as dangerous to breathe when wet as when dry. Veasey (29a) describes in detail the course of the air in the present-day Leyner.

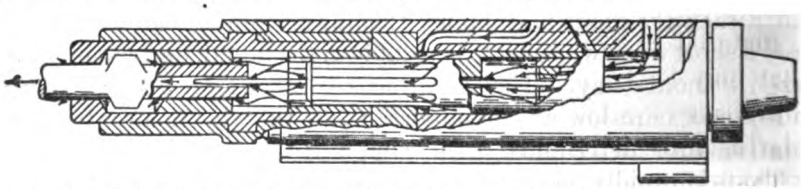

FIGURE 2.—Longitudinal section through a typical modern Leyner drill. (After Veasey (29a)

Figure 2 is a longitudinal section, through a typical modern Leyner machine. The arrows indicate the paths by which air from the working cylinder reaches the chuck cavity and the hollow steel. From the rear end of the cylinder the path is along the flutes of the rifle bar and thence through the bore of the piston on the outside of the axial tube. From the front end of the cylinder, air passes along the flutes of the piston intermittently while the machine is working, but in a strong blast the steel jams in the hole and stalls the machine.

Of course the whole of the air to reach the chuck cavity does not pass down the hollow steel, because an alternative path for it is between the shank and the chuck bushing; this path varies with wear.

Experiments carried out in South Africa showed that sludging with water alone could be effective in sinking as well as in development work, provided the hole in the steel was large enough and the water pressure sufficiently high. On the basis of these studies, to avoid the air blow system of sludging as in the Leyner drill, the "long piston drill" has been developed in which water alone is used. The changes made in

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the drill are indicated in Figure 3, in which (*a*) indicates the smooth part of the piston between the flutes and the head so lengthened that the flutes never enter the cylinder; (*b*) shows the front-head washer lengthened by a similar amount, and, of course, made a good working fit on the piston; (*c*) indicates where, for 2 inches, the axial bore of the piston is made to be a good working fit on the axial tube; and (*d*) shows exhaust holes to atmosphere from the front part of the machine. These holes discharge any air that may leak past (*b*) and (*c*) and so prevent it from entering the hollow steel.

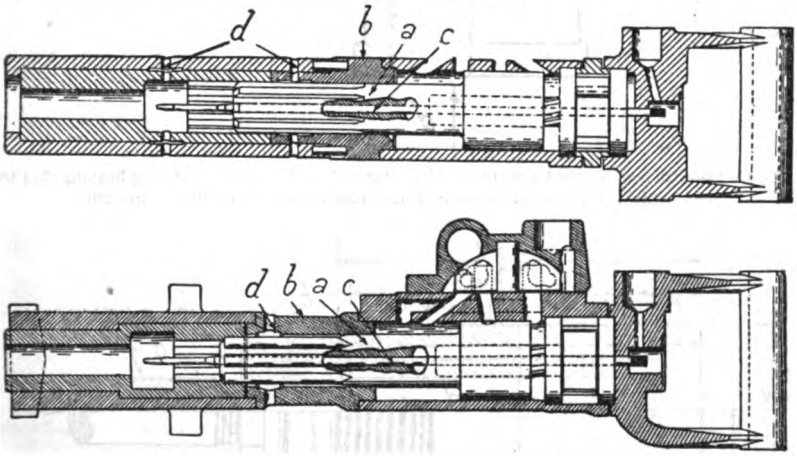

FIGURE 3.—Longitudinal section through a long-piston Leyner drill. (After Veasey (29a.) See text for explanation of letters

WATER SPRAYS

In addition to the use of wet drilling, all working places and passages should be thoroughly wet with water; and water should be used on all material, whether blasted down, being shoveled, or being moved in ore chutes or pockets. Clean water should always be used to lay dust, as particles of dust from a spray may be left in suspension in the atmosphere.

Hose, sprays, atomizers, and water blasts are used to eliminate dust. The hose and sprays operate under water pressure only. Water from the end of a hose does not remove much of the dust already in the air, but can be used to advantage to wet down rock piles or wash down the sides and roof. The water spray produces a shower of droplets and distributes the water well over all surfaces, but the water is not finely enough divided to remove much of the dust from the air. Atomizers and water blasts operate under water pressure with air pressure—the air breaking the water up into very fine clouds or mist. A great surface of water is thus produced and dust in the air is wetted and settles more quickly.

Many types of these devices have been developed (30); some of these are shown in Figures 4, 5, 6, and 7.

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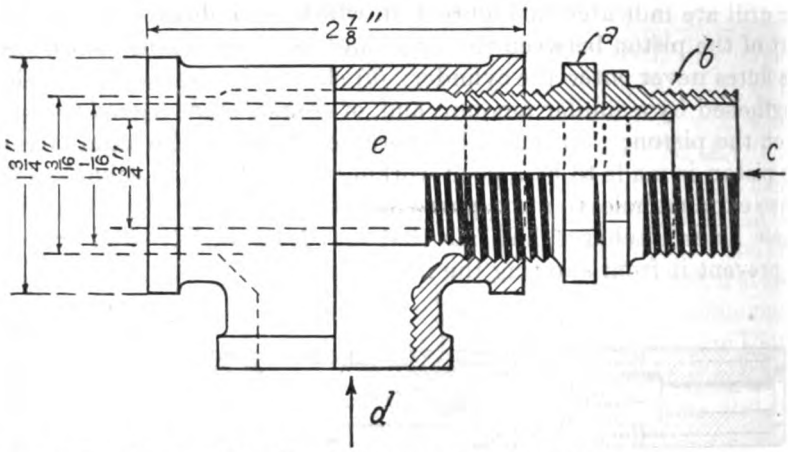

FIGURE 4.—Detail of a water blast with malleable cast-iron T: *a*, 1 to ¾ inch reducing bushing; *b*, 1 to ¾ inch reducing bushing, malleable cast-iron; *c*, air; *d*, water; *e*, ¾-inch pipe (20)

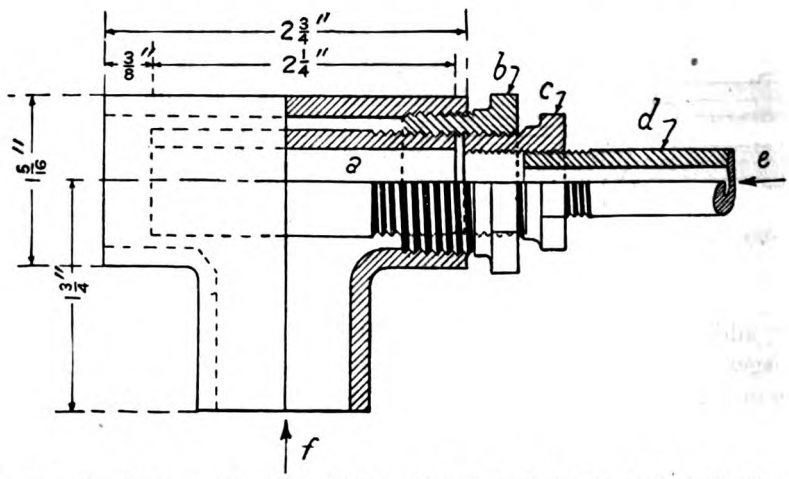

FIGURE 5.—Detail of a water blast with an iron T: *a*, ½-inch nipple; *b*, ¾ to ½ inch reducing bushing; *c*, ½ to ¼ inch reducing bushing; *d*, ¼-inch pipe; *e*, water; *f*, air, (20)

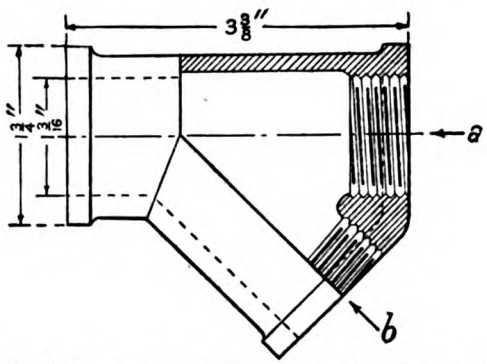

FIGURE 6.—Detail of a water blast with a malleable cast-iron Y: *a*, air; *b*, water (20)

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WATER BLASTS

Water blasts are especially useful for wetting down the roof, sides, and floor as well as the ore piles. As shooting probably produces more dust than any other operation, a water blast should be turned on immediately before firing begins and should be continued for at

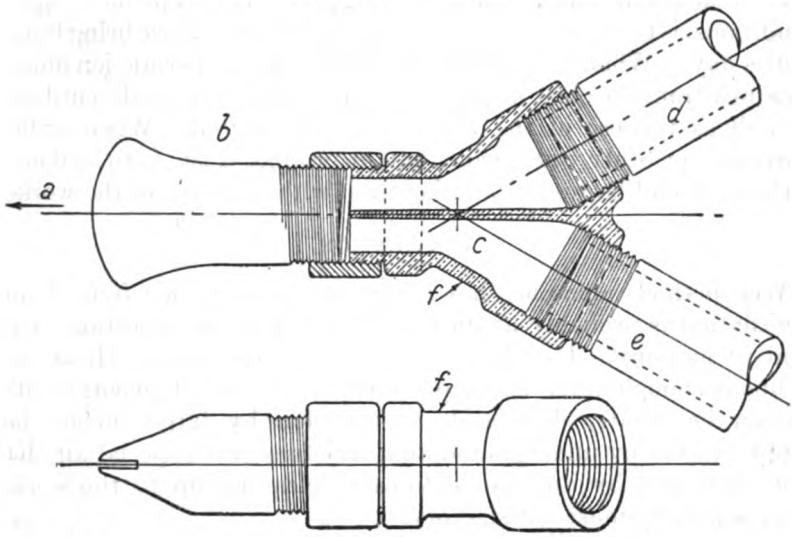

FIGURE 7.—The crown atomizer: *a*, direction of blast; *b*, ¾-inch pipe flattened out to form nozzle; *c*, diaphragm; *d*, ¾-inch air pipe; *e*, ¾-inch water pipe; *f*, brass Y piece (20)

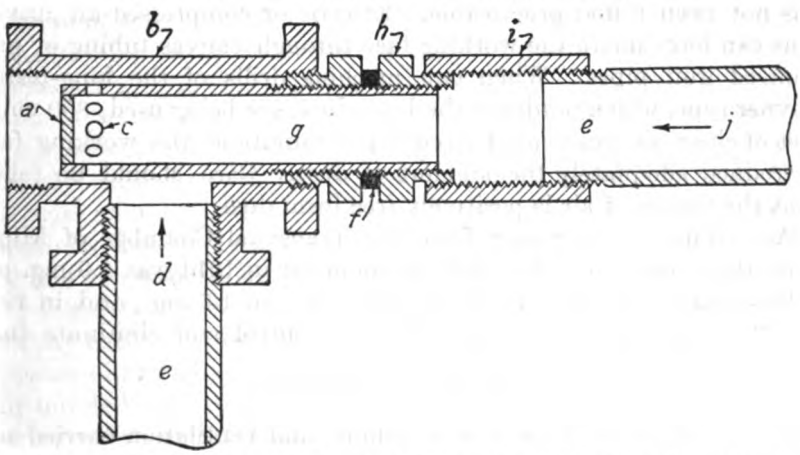

FIGURE 8.—Suggested design for a water blast made from standard pipe fittings: *a*, Plug welded in; *b*, 1-inch T; *c*, 8 ⅛-inch holes (a second row of ⅛-inch holes back of those shown is of advantage); *d*, entrance of water; *e*, 1-inch pipe; *f*, gasket; *g*, ¾-inch pipe; *h*, ¾-inch by 1-inch bushing; *i*, 1-inch sleeve coupling

least 30 minutes, that is, until all rock and surfaces are thoroughly wetted. (Pl. X, *C* and *D*, p. 15.) The water blast should be placed within 50 to 100 feet of the face to be blasted and should be protected from the flying rock by a shield made of iron about ½ inch thick

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and about 12 to 15 inches square. Figure 8 shows a suggested design for a water blast made from standard pipe fittings.

Shots should be fired only at the end of a shift, and no one should be permitted to go into the working places until the air has been thoroughly freed from dust. The time required to free the air of dust will vary with conditions. South African practice, except under special conditions, is to allow firing only at the end of shift, there being but one shift a day. When more shifts are worked, special permission must be obtained from the chief inspector of mines, and increased ventilation, as well as the use of the water blast, is required. When drilling, shoveling, or other work, which might produce dust, is to be done all surfaces should be wetted and kept wet within 25 feet of the workers.

VENTILATION

Wet methods alone are not enough to keep the air free of dust. Ventilation is probably as important, if not more important, a preventive measure. If the dusty air can be replaced by clean air at frequent enough intervals, opportunity for the development of silicosis can be greatly decreased. Ventilation by large surface fans, supplemented by underground auxiliary fans, with special air shafts and controlled by doors so as to carry clean air up to the working face, is usually most satisfactory.

In this country (11) and in South Africa (16) to remove the dust, produced by drilling, by ventilating with compressed air alone has not been found practicable. Electric or compressed-air driven fans can force air to the working face through canvas tubing or galvanized iron pipes. When two machine drills of the long-piston Leyner type, which produces the least dust, are being used, 800 cubic feet of clean air must be delivered per minute at the working face to reduce adequately the amount of dust. Care should be taken that the source of air is positively free from dust.

According to the report from the Transvaal Chamber of Mines (27), the average dust found in the mine air in 1914 was 4.9 mg. per cubic meter. In 1922 the figure had fallen to 1.6 mg., and in 1923 to 1.3, as a result of constant effort to control and eliminate dust.

PHYSICAL EXAMINATIONS

Even with the wet methods of mining and ventilation carried out as they have been up to the present time, silicosis, although it has been lessened, has not been eliminated. Respiratory diseases predispose to silicosis. Physical examinations of workers have been required by law in Australia, South Africa, and Great Britain; there a workman must be examined before he begins work in certain mines or in certain trades (Great Britain), and at regular periods of 6 to 12 months thereafter.

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The first examination is made to determine whether the applicant has any disease, especially of a respiratory nature, which would make him susceptible to silicosis or tuberculosis. Any man suffering with silicosis should not be employed where he will have to breathe dust, especially silica dust. In general, he should not be employed underground. If he has tuberculosis, he should not be allowed underground at all. Men with tuberculosis develop silicosis much more rapidly than do normal men and their tuberculosis progresses much more rapidly when they are exposed to silica dust. Also, men having silicosis are very susceptible to tuberculosis. It is, therefore, of the greatest importance that they come in contact as little as possible with people having tuberculosis.

At the periodic examination, any man found to be suffering with silicosis, which usually can be diagnosed in a very early stage, should be notified in order that he may seek other employment, if he so desires. As a protection to other workers as well as to himself, any man found suffering with tuberculosis should not be allowed to return to mining. In the countries where physical examinations are compulsory under the law, compensation is provided for those found to have either silicosis or tuberculosis, or both. As a result, in South Africa, where all precautions have been taken, no cases of silicosis have developed from August 1, 1916, to May 1, 1923, among 5,234 recruits who passed the initial examination and became miners on the Rand (26).

In some countries the physical examinations are made by a national medical bureau constituted for the purpose. In other countries the men best qualified in various districts are appointed by the Government to make the examinations. In still others, a board consists of a medical man appointed by the State, one selected by the industry, and a third by the employees. The man selected to make these physical examinations should be experienced in respiratory diseases, especially those caused by dust, should be acquainted with the industry and the conditions under which the men must work, and should be neutral, that is, should favor neither the employer nor the employee. In time these men become the most experienced and expert on these diseases of any physicians in the country. However experienced and fair-minded they may be, occasionally either the employer or the worker wants an appeal, which can usually be made only to the board itself. The examination of the man in question is made by another member of the board without the examiner being acquainted with the fact that an appeal has been made. The findings of the two physicians are then reviewed by conference of the entire board.

Physical examination is believed to be very important for prevention of silicosis, as well as tuberculosis, but it must be remembered that no one measure is successful. A combination of all preventive

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measures—wet methods of mining (wet drilling, the use of sprays and water blasts), good ventilation, and initial and periodical physical examination are needed to prevent silicosis.

SUMMARY

1. Silicosis or miners' phthisis has been known to occur among miners in certain districts for centuries.

2. Silicosis is found among metal miners in New Zealand, Australia, South Africa, Great Britain, and in many of the States of the United States.

3. Silicosis is due to breathing very fine rock dust. Rock dust high in free silica is found to be most injurious.

4. Silica dust is somewhat soluble in water and in weakly alkaline liquids similar to body fluids.

5. Some physicians have thought that silica dust by its sharp-edged and needlelike particles injures the lung tissue mechanically. Another belief is that the silica, being soluble in water and weakly alkaline liquids, (5) injures lung tissue by its poisonous action.

6. The rate of development of silicosis depends upon the character of the dust, the amount breathed, length of exposure, past illness (especially tuberculosis), and physical fitness of the men.

7. Among gold miners in South Africa the average length of exposure to silica dust before silicosis develops is 7½ years, the shortest period of exposure for like results is 2½ years.

8. Silicosis is usually divided into three stages: The first shows symptoms and physical signs of damage to lung tissue caused by exposure to dust, but capacity for work is not impaired. The second stage shows definite signs of silicosis and capacity for work is impaired, although not seriously or permanently. The third stage shows that specific signs of silicosis are or have been present and the capacity for work has been seriously and permanently impaired by the disease.

9. The cardinal symptom of silicosis is shortness of breath, especially on exertion. The cardinal sign is diminished expansion of the chest. Both are slight in the early stages and increase gradually with development of the disease. Other symptoms and signs, as coughing, frequent colds, pains in the chest, and X-ray findings, are very important in making a diagnosis.

10. Men having silicosis are more susceptible to tuberculosis than normal men.

11. Men with silicosis can improve in suitable surroundings to recovery in the first stage, can improve materially in the second stage, and somewhat in the third stage.

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12. Many methods for determining the amount of dust in the air are available. The sugar tube method, the konimeter, and the impinger are chiefly used in the mining industry in the United States.

13. The elimination of silicosis among miners depends on preventing the formation of dust by wet mining methods—wet drilling and wetting sides, roof and bottom, muck, and rock piles; the use of sprays and water blasts to lay the dust after blasting; good mechanical ventilation to replace dusty air with clean air; and physical examination of all miners before employment and periodically thereafter.

14. All of these means of prevention must be practiced to insure success.

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